April 25, 1861.

Major-General SABINE, R.A., Treasurer and Vice-President, in the Chair.

The following communications were read:—

I. "On the Distribution of Aqueous Vapour in the upper Parts of the Atmosphere." By Lieut.-Col. RICHARD STRACHEY, F.R.S. Received March 25, 1861.

The experiments of chemists having shown that any gas will flow into a space occupied by another gas, and diffuse itself there as though the space were a vacuum and the second gas not there, it was suggested by Dalton that the atmosphere might be considered to be a combination of as many distinct atmospheres as it has gaseous components, and that the actions of each of these might be treated of separately, and irrespective of the others. Meteorologists, pursuing this idea, have proposed to separate the pressure of the aqueous vapour from the whole barometric pressure of the atmophere, and thence to infer the pressure of the permanently elastic portion, or as it has been called, the *Gaseous Pressure*, or the *Pressure of the Dry Air*.

It is my object to inquire how far the facts of the matter will support Dalton's suggestion of the possible independent existence of an atmosphere of aqueous vapour, and whether we can in truth eliminate the pressure of this vapour by subtracting the observed tension from the total barometric pressure, in the manner that has commonly been done of late years.

And first as to the hypothesis of an atmosphere of aqueous vapour pressing only upon itself. If there be such an atmosphere, the general laws of pressure of elastic fluids will apply to it, as they do to the mixed atmosphere. But in consequence of the small specific gravity of the vapour, the rate of the diminution of pressure in the upper strata of the vapour atmosphere would be much slower than in the mixed atmosphere; and irrespective of any variation in the law of the decrease of temperature, the height to which we should have to ascend in the vapour atmosphere to produce a given diminution of pressure, would be to the corresponding height in the mixed atmo-

sphere inversely as the specific gravities of the atmospheres, that is, as 1 to ·625 or as 8 to 5. Thus by ascending about 19,000 feet in the atmosphere, the barometric pressure is found to be reduced one-half; and consequently it would be necessary to ascend to about $\frac{8}{5}$ of 19,000 feet, or upwards of 30,000 feet, to produce a corresponding diminution of pressure in a vapour atmosphere, or to reduce the tension, say from 1 inch to $\frac{1}{2}$ an inch.

Now let us compare this result with the observed facts. This is done in the annexed Table I., in which the ratio of the tensions of the vapour at heights extending to 20,000 feet with the surface tension, as actually observed, is set down in juxtaposition with the ratios that should hold good in an independent vapour atmosphere. We here see that in reality the tension is reduced to one-half of what it is at the earth's surface by an ascent of about 8000 feet, instead of 30,000 feet, as the hypothesis of the independent vapour atmosphere would require.

Table I.

Comparison of Tensions of Dalton's Hypothesis with those actually observed.

Height above the earth's surface in feet.	Barometric pressure of the entire atmosphere.	Calculated tensions in atmosphere of aqueous vapour alone, that at the earth's surface being 1·0.	Ratio of tensions to surface tension actually observed.		
			By Dr. Hooker on the Himalaya.	By Mr. Welsh in four balloon ascents.	At Dodabetta & Mahabaleshwar (fide Col. Sykes).
	in	in.			
0	30·0	1·00	1·00	1·00	
2,000	28·0	·96	·82	·88	
4,000	26·1	·92	·68	·77	·67
6,000	24·3	·88	·62	·58	
8,000	22·6	·84	·52	·45	·47
10,000	21·0	·80	·42	·35	
12,000	19·5	·77	·35	·30	
14,000	18·0	·73	·29	·19	
16,000	16·6	·70	·25	·18	
18,000	15·3	·67	·20	·16	
20,000	14·1	·64	·16	·12	

The facts, as indicated by the long series of observations, of which the Table contains an abstract, are altogether in accordance with the results of my own observations; but I have thought it better to rest my conclusions on the facts observed by others. Further, the discrepancy between the observations and the hypothesis is so great, and so constant with reference to all the localities, the Himalaya, En-

gland, and the mountains of the south of India, while the observations are themselves so thoroughly consistent, that the conclusion is inevitable that the hypothesis is untenable.

A similar conclusion as to the entire incompatibility of the hypothesis of a separate vapour atmosphere with the facts, may be drawn quite independently of any observation of tensions, from a mere consideration of the known laws of the diminution of temperature as we ascend. An argument, something to this effect, will be found in Bessel's paper on Barometric Heights *; but its form being too mathematical to be generally intelligible, I shall endeavour to place the matter in a rather more popular point of view.

Let us suppose, then, that we are at a place at the sea-level where the temperature of the air is 80°, the tension of vapour being ·80, which would make the dew-point 72°·5—a case that must be of constant occurrence. If, now, we rose gradually above the earth's surface, the temperature of the air would be reduced at the known rate of about 3° for 1000 feet; while the tensions of vapour, and the corresponding dew-points, calculated upon the hypothesis of an atmosphere of vapour pressing upon itself, would be as follows :—

	ft.						°			°
At	0	..	Tension	·80 ..	Dew-point		72·5	..	Air	80·0
	1000	..	,,	·78 ..	,,		71·8	..	,,	77·0
	2000	..	,,	·77 ..	,,		71·2	..	,,	74·0
	3000	..	,,	·75 ..	,,		70·5	..	,,	71·0
	4000	..	,,	·74 ..	,,		69·9	..	,,	68·0

Hence, up to about 3000 feet, the temperature of the air would be found to be higher than the dew-point, and the supposed tensions might of course exist. But the temperature of the air, it will be seen, diminishes much more rapidly as we ascend than that of the dew-point; and the former will therefore soon fall below the latter. Thus at 4000 feet, the air being at 68°, the theory demands vapour, with a dew-point of 69°·9, which is impossible; for any vapour, in excess of that corresponding to the air temperature 68°, would be instantly precipitated. In like manner it might be shown that, under all conceivable conditions of heat or cold, and of damp or dryness at the surface of the earth, we could always ascend to a height where

* Astronomische Nachrichten, Nos. 356, 357; and Taylor's Scientific Memoirs, vol. ii. p. 517.

the diminution of temperature would render the progression of the tensions according to the presumed law impossible. We may therefore conclude generally, that the known diminution of temperature in the atmosphere is incompatible with the existence of so large a quantity of vapour in the upper strata as the theory in question demands; and, consequently, that the tensions observed at the surface are neither dependent on, nor balanced by, the pressure of the vapour in the higher parts of the atmosphere (in the way in which the entire barometric pressure depends on the weight of the whole superincumbent column of air), for this would be insufficient to produce them. To render an independent vapour atmosphere possible would, indeed, require a fall of temperature in the air of about 1° for 1500 feet, or less than a quarter of that which really takes place.

It will also follow that, as the tension of vapour at any point exceeds the sum of all the pressures of the vapour above it, it must in part be due to the reaction of the air particles, which must therefore press upon those of vapour, contrary to the supposition with which we started. This is, in fact, equivalent to saying that the air offers a resistance to the diffusion of vapour, instead of having no effect whatever in obstructing it; and thus from an erroneous assumption, based upon experiments made on very small quantities of air in confined vessels, arises the fallacy of the theory I have been considering.

I am aware of no systematic observations relative to the actual distribution of vapour in the atmosphere, excepting those made by Dr. Joseph Hooker, and published in his Himalayan Journals*. He found in his journeys in Sikim, which extended to heights of 18,000 feet and upwards, that the quantity of vapour was dependent rather on the temperature of the air than on anything else, and that it was, in fact, simply a certain proportion of the maximum quantity that can exist in accordance with the conditions of temperature at any altitude, the relative quantity being pretty nearly constant throughout the whole column. These conclusions of Dr. Hooker are altogether corroborated by my own observations. In the annexed Tables I have further illustrated this. In Table II. I have shown for a considerable range of temperature at the earth's surface, the proportion of vapour that would be found at various heights in the atmo-

* Himalayan Journals, vol. ii. p. 422.

sphere, as compared to that at the surface (which is in each case assumed to be represented by 1·0), supposing the air to be everywhere saturated with moisture, and the reduction of temperature for ascent to be 3° for 1000 feet. To these calculated ratios are added those actually observed by Dr. Hooker in the Eastern Himalaya, and by Mr. Welsh in his balloon ascents*, as already given in a preceding page.

TABLE II.

Proportion of Vapour at various Altitudes.

Height in feet.	Calculated, the temperature of air at the surface being				Observed,	
	80°.	60°.	40°.	20°.	By Dr. Hooker, in Sikim—Therm. at sea-level being 70° to 90°.	By Mr. Welsh, in a Balloon—Therm. at surface being 50° to 70°.
0	1·00	1·00	1·00	1·00	1·00	1·00
2,000	·82	·81	·79	·77	·82	·88
4,000	·67	·65	·62	·58	·68	·77
6,000	·54	·52	·48	·44	·62	·58
8,000	·44	·41	·36	·34	·52	·45
10,000	·35	·32	·28	·26	·42	·35
12,000	·28	·25	·21	·19	·35	·30
14,000	·22	·19	·16	·14	·29	·19
16,000	·18	·15	·12	·10	·25	·18
18,000	·14	·12	·09	...	·20	·16
20,000	·11	·08	·07	...	·16	·12

In Table III. the results of Dr. Hooker's and my own observations are given in more detail.

The accordance between the calculated and observed quantities of vapour shown by these figures is so close, that we can have no hesitation in admitting that Dr. Hooker's conclusion will, in all probability, be found to afford the general solution of this problem. The relative quantity of vapour in the case of his observations having been rather greater in the higher than in the lower strata of the atmosphere, is a circumstance which cannot be held to affect the general truth of our conclusions, as will be perfectly accounted for by supposing that the diminution of temperature with height was less rapid in reality, than 3° for 1000 feet, on which my calculation is based. It is further worthy of notice, that the calculated proportion of vapour at various altitudes varies but little even with considerable change of the surface temperature, though there is a manifest ten-

* Phil. Trans. 1853, p. 311.

Table III.

Ratio of Tensions observed at various Altitudes on the Himalaya to the Tension at the Sea-level.

Heights.	Jan.		Feb.		March.		April.		May.		June.		July.		August.		Sept.		Oct.		Nov.		Dec.		Mean.		General mean by observations.	Theoretical ratio by calculation.
	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.		
Sea-level	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00	1·00
1 to 2,000 feet......	·95	·83	..	..	·70	..	·70	·90	·69	..	..	..	..	..	..	..	..	·82	..	..	·89	..	·85	..	·80	·85	·81	·86
3,000 ,, ...	..	·89	..	·85	..	..	..	·71	·64	..	..	·89	..	..	..	..	..	·86	..	·73	·78	..	·92	..	·78	·82	·81	·78
4,000 ,, ...	·78	..	..	..	..	..	..	·83	·62	..	..	..	..	..	..	..	..	..	·58	..	·67	·81	·71	..	·67	·82	·71	·71
5,000 ,, ...	·70	..	..	..	·48	..	..	·78	·49	..	..	·75	..	·72	..	..	..	..	·55	·70	·76	·67	·67	..	·61	·72	·66	·64
6,000 ,, ...	·58	·58	..	·54	..	·69	..	·71	·53	·67	..	·61	..	·65	·68	·62	..	·60	..	·60	·75	·58	·63	·74	·63	·63	·63	·57
7,000 ,, ...	·58	..	·58	..	..	..	..	·68	·54	..	..	·65	..	·60	·58	·59	..	·60	·48	·60	..	..	·58	..	·56	·62	·59	·52
8,000 ,, ...	·55	..	·46	..	·45	..	·43	·63	·45	..	·50	·53	·57	..	·56	..	·53	..	·48	·46	·60	..	·48	..	·51	·54	·51	·47
9,000 ,, ...	·48	..	..	·36	..	·61	·37	..	·46	..	·45	·47	·46	..	·52	..	..	..	·40	·40	·49	..	..	..	·45	·46	·46	·42
10,000 ,, ...	..	..	..	..	..	..	..	..	..	..	·34	·49	..	..	..	..	..	..	..	·36	·42	..	·48	..	·41	·43	·42	·37
11,000 ,, ...	..	..	..	..	..	..	..	..	·37	..	·36	·36	·38	·40	..	..	..	..	·36	·47	·42	..	·35	..	·37	·41	·39	·34
12,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	·34	·39	·32	·39	·33	·38	·34	·28	·29	·36	..	·38	..	·36	·36	·35	·30
13,000 ,, ...	..	..	..	..	..	..	..	..	..	..	·37	·36	..	·29	..	·32	..	..	·31	..	·27	..	..	..	·32	·32	·32	·27
14,000 ,, ...	..	..	..	..	..	..	..	..	..	..	·33	..	..	·23	·31	..	..	..	..	..	·20	..	·23	..	·27	·23	·26	·24
15,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	·16	..	·21	..	·23	..	·17	..	..	..	..	..	·19	·19	·21
16,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	·16	·29	·13	·29	·13	·26	..	..	..	·23	..	·27	·14	·21	·19
17,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	·14	·26	·18	·17	..	·16	..	·09	..	·23	..	·18	·16	·18	·17
18,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	·15	..	..	·21	..	..	..	..	..	..	..	·21	·15	·18	·15
19,000 ,, ...	..	..	..	..	..	..	..	..	..	..	..	..	..	·14	..	·15	·22	..	·13	..	..	..	..	..	·18	·15	·16	·13

Notes.

A. Ratios from observations by Dr. Hooker in Sikim, referred to Calcutta.

B. Ratios from observations by Lieut.-Col. Strachey in Kumaon, referred to Fatehgarh.

The Theoretical ratios are calculated as explained; the temperature at the surface being taken as 80°, and the decrement 3° in 1000 feet.

dency for the upper strata to contain a rather higher per-centage with a high than with a low temperature; a result likewise in accordance with fact, so far as we are able to judge from the comparison of Dr. Hooker's Indian observations with those made in England by Mr. Welsh.

The precise determination of the entire pressure of the vapour thus shown by observation to be suspended in the atmosphere is a matter of some difficulty; but an approximation may be made to it as follows:—

Let us suppose the weight of the vapour to be measured, as is often done in the case of the entire atmosphere, by the height of a column of the density observed at the surface. The height of a homogeneous atmosphere of vapour, equivalent to an independent vapour atmosphere, on Dalton's hypothesis would obviously be $\frac{8}{5}$ of the height of the homogeneous air atmosphere, that is $\frac{8}{5}$ of 26,250 feet, or about 42,000 feet.

But the vapour actually existing is much less than this. Taking the results of Dr. Hooker's observations, and considering the density at the surface to be unity, the mean density of the whole vapour below 20,000 feet will readily be calculated to be about ·47; so that the whole of the vapour up to this height would be equivalent to a homogeneous column of 9460 feet of density 1·0. Now it may be assumed approximately that the quantity of vapour above 20,000 feet will bear the same relation to the entire quantity, as holds good between the densities at that height and at the surface; and as we see from the Table that the density at 20,000 feet is $\frac{16}{100}$ of what it is at the surface, we may infer that this is the proportion of the vapour above that altitude, the remainder, or $\frac{84}{100}$, being below it. Consequently the whole quantity of vapour, according to Dr. Hooker's observations, would be equivalent to a homogeneous column of $\frac{100}{84} \times 9460$, or 11,260 feet. Using the balloon observations, the height would be rather less than this, viz. 10,050 feet, so that we may infer that the actual pressure of the vapour in the atmosphere is to that represented by the tension at the surface of the earth, as 10,500 to 42,000, or as about one to four; and this ratio would also subsist between the actual pressures and observed tensions at all elevations.

The problem might otherwise be solved, by comparing the diminution of density as we ascend, according to Dalton's hypothesis,

and the observations, as shown by the series of figures in Table I. This diminution, it will be seen, takes place in all the series, approximately in a geometrical ratio, so that the density is reduced nearly in an equal proportion for each 2000 feet of ascent, namely, from 1·00 to ·96, that is by $\frac{4}{100}$, on Dalton's hypothesis; from 1·00 to ·84, that is by $\frac{16}{100}$, according to Dr. Hooker; and from 1·00 to ·82, that is by $\frac{18}{100}$, according to Mr. Welsh. Now it follows, from an obvious mathematical law, that the entire quantities of vapour in these different cases are inversely proportional to the constant reduction of density; so that the quantity on Dalton's hypothesis, which is that represented by the observed tension at the surface, is to the quantity according to Dr. Hooker, as sixteen to four, and to the quantity according to Mr. Welsh, as eighteen to four, a result nearly identical with the former. The subtraction of the observed tension of vapour from the total barometrical pressure, in the hope of obtaining the simple gaseous pressure, must consequently be denounced as an absurdity; and the barometrical pressure thus corrected, as it is called, has no true meaning whatever.

In conclusion, I would remark that the consideration of the small quantity of vapour that is disseminated in the upper parts of the atmosphere, shows us that inequalities of level on the earth's surface, which are insignificant when viewed in relation to the dimensions of the globe, become objects of the greatest importance in connexion with the atmosphere which surrounds it. Three-fourths of the whole mass of the air is within range of the influence of the highest mountains; one-half of the air and nearly nine-tenths of the vapour are concentrated within about 19,000 feet of the sea-level, a height which hardly exceeds the mean level of the crest of the Himalaya; while one-fourth of the air and one-half of the vapour are found below a height of 8500 feet. Thus, mountains even of moderate magnitude may produce important changes in very large masses of the atmosphere, as regards their movements, their temperature, and their hygrometric state; and especially in those strata that contain the great bulk of the watery vapour, and that have the greatest effect therefore in determining the character of climate.